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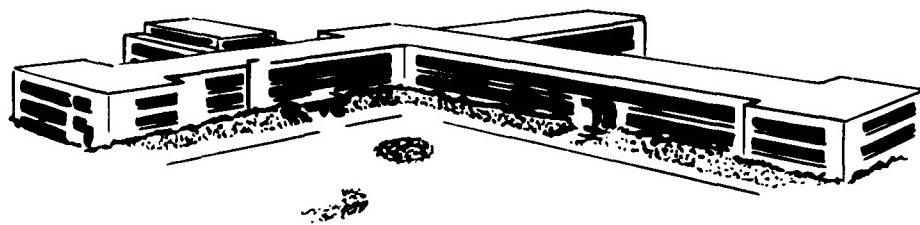
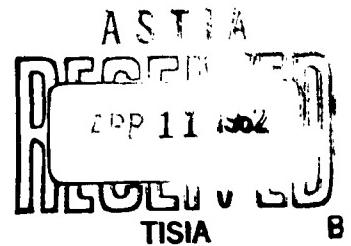
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290-F

DATA ANALYSIS AND LONG RANGE
INTERCEPT TECHNIQUES

H B



HRB-SINGER, INC.
Science Park, State College, Pa.
A SUBSIDIARY OF THE SINGER MANUFACTURING COMPANY

AD _____ DIV NO. _____	UNCLASSIFIED	AD _____ DIV NO. _____	UNCLASSIFIED
HRB-Singer, Inc. Report No. 290-F State College, Pennsylvania	1. Equipment 2. Amplifiers 3. Parametric Amps	HRB-Singer, Inc. Report No. 290-F State College, Pennsylvania	1. Equipment 2. Amplifiers 3. Parametric Amps
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HRB-SINGER, INC.
State College, Pennsylvania

290-F

DATA ANALYSIS AND LONG RANGE INTERCEPT TECHNIQUES

FINAL REPORT

21 March to 21 December 1961

RESEARCH AND DEVELOPMENT ON
PHASE SHIFT AMPLIFIERS IN
THE 50-1100 Mc BAND

CONTRACT DA 36-039-SC87272
FILE NO. 40047-PM-61-91-91-(1103)

Prepared for

U. S. Army Signal Research and Development Laboratory
Fort Monmouth, New Jersey

Copy No. 21 of 68 Copies

Prepared by:

E. Wintermute
V. Rathfelder

Submitted by: *John D. Wintermute*

E. Wintermute
Project Director

Approved by: *R. L. Parson*

for C. L. Welch
Manager, Measurement
& Development Section

PURPOSE

The purpose of this contract is to conduct studies and investigations of "Data Analysis and Long Range Intercept Techniques." The effort covered in this report consisted of measurements and experimentation on the phase shift amplifier in the 50 to 1100 megacycle band.

ABSTRACT

The results of nine months of research on the phase shift amplifier are reported. Two experimental models constructed during this effort are described, and the problems encountered during their development are discussed.

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I. PUBLICATIONS, LECTURES, REPORTS AND CONFERENCES

A. CONFERENCES

1. Date - 23-24 March 1961

Place - Evans Signal Laboratory

Participants -

ASA HRB-Singer, Inc.

Lt. Crafton A. F. Lopez
E. H. Wintermute

Cooley Electronics Lab. ESL

D. K. Adams H. Brett
S. Stiber

Subject of Discussion

Mr. D. K. Adams presented a briefing on his theoretical analysis of the phase shift amplifier, after which his suppositions and conclusions were discussed.

After the completion of the above presentation, the commencement of contract DA-36-039-sc-87272 was discussed. Lt. Crafton requested that the early months of the effort be spent developing an experimental field model in the 50 to 150 Mc band. (HRB-Singer, Inc. had previously built and tested a laboratory model in this band). This request was agreed to by those concerned.

2. Date - 20-21 April 1961

Place - HRB-Singer, Inc.

Participants -

HRB-Singer, Inc. ESL ASA

A. F. Lopez H. Brett Lt. W. Crafton
R. L. Passow
R. L. Sherry
E. H. Wintermute

Subject of Discussion

A general discussion was held on the progress of the contract and direction of future effort. After the completion of this discussion the group

moved to the laboratory to attempt to reproduce an apparently anomalous phenomenon that had been previously observed when the phase shift amplifier was pumped at X-band. When the amplifier was tuned in a certain way, it was possible to read an apparent receiver sensitivity 20 db superior to the maximum theoretical sensitivity. After it was noted that this apparent sensitivity was unaffected by removal of the varactor from the amplifier, the amount of X-band energy in the Signal Generator Attenuator (waveguide below cut-off) was measured at approximately -10 dbm by placing a small probe into the attenuator. It was thus concluded that the apparent -140 dbm sensitivity resulted from the modulation of this X-band energy inside the signal generator, thus allowing the signal to traverse the attenuator with far less than the -140 db indicated by the dial reading.

3. Date - 8 June 1961Place - HRB-Singer, Inc.Participants -HRB-Singer, Inc.ESLASA

R. N. Norris

H. Brett Lt. W. Crafton

R. L. Passow

E. H. Wintermute

Subject of Discussion

Shortly before this conference, the initial construction of the 50 to 150 Mc amplifier was completed. Laboratory testing had begun, and revealed two problems which had not been anticipated, since they had not been encountered in any previous model constructed by HRB-Singer, Inc. The over-all noise figure of the PSA - transistor post amplifier configuration was 6 db, where 2 to 3 db was anticipated. It was also determined that the amplifier would go into oscillation when fed with an antenna rather than directly from a signal generator.

It was expressed that the high noise figure seemed to come from an apparent increase in the post amplifier noise figure, and that this problem was being given priority over the antenna difficulties, since low noise is the chief merit of the phase shift amplifier.

These problems were discussed and demonstrated in the laboratory, and the general plan of attack in solving them was outlined.

4. Date - 2-3 August 1961

Place - Evans Signal Laboratory

Participants -

ASA

HRB-Singer, Inc.

ESL

Lt. Maino

E. H. Wintermute

H. Brett

Sp-3 Devereaux

A. Digiocomo
A. Resnick
S. Stiber

Subject of Discussion

The primary purpose of this trip was to deliver an experimental model of the phase shift amplifier. This model, the "515-PSA," was a band pass amplifier covering 50 to 150 megacycles. The experimental model was subjected to a number of laboratory tests by the personnel at Evans Signal Laboratory. Its performance was approximately as would be predicted on the basis of its noise figure, gain and bandwidth. Lieutenant Maino and Specialist Devereaux were briefed on the operation, alignment, and maintenance of the model 515-PSA.

5. Date - 19 September 1961

Place - Evans Signal Laboratory

Participants -

HRB-Singer, Inc.

ESL

L. E. Hargenrader

H. Brett

R. L. Passow

C. L. Welch

E. H. Wintermute

Subject of Discussion

The general status of the contract was discussed with regard to establishment of priorities for the remainder of the contract. The merits of concentrating primarily on the higher bands were pointed out. Administrative changes which would further involve Messrs. Welch and Hargenrader in the contract were explained.

6. Date - 2-3 November 1961

Place - HRB-Singer, Inc.

Participants -

ASA

HRB-Singer, Inc.

ESL

Lt. Eisenhart

C. Welch

H. Brett

E. Winternmute

Subject of Discussion

The results of the contract in its first seven months were discussed, as well as the intended effort during the final two months. The problems involved in pumping a 300 to 600 Mc experimental model were indicated, and the general layout of a 150 to 300 megacycle experimental model was outlined.

B. PUBLICATIONS AND REPORTS

1. 290-L-1 First Monthly Letter Report dated 26 April 1961
2. 290-L-2 Second Monthly Letter Report dated 26 May 1961
3. 290-L-3 Third Monthly Letter Report dated 25 July 1961
4. 290-L-4 Fourth Monthly Letter Report dated 24 August 1961
5. 290-L-5 Fifth Monthly Letter Report dated 18 October 1961
6. 290-L-6 Sixth Monthly Letter Report dated 30 November 1961
7. 290-1 First Quarterly Report dated 20 July 1961
8. 290-2 Second Quarterly Report dated 20 October 1961
9. 290-M-1 Instruction Manual for Model 515PSA dated 1 August 1961
10. 290-M-2 Instruction Manual for Model 1530 PSA dated 15 February 1961

These reports were prepared by E. H. Winternmute.

II. FACTUAL DATA

A. GENERAL

The work accomplished in the course of this contract can be summarized as the achievement of three goals: Two experimental models of the phase shift amplifier were developed, availability of gain was confirmed in the laboratory throughout the 50 to 1100 megacycle band, and the intermodulation and cross-modulation characteristics of a 250 to 500 megacycle laboratory model were measured.

B. DEVELOPMENT EFFORT

The development of the experimental models was the largest effort, in terms of time spent, during the course of the contract. Approximately 6 months of the 9 month contract were expended in the development phase.

1. 50 to 150 Megacycle Model

The first experimental model was called the 515 PSA. This unit consisted of a phase shift amplifier with 10 db gain followed by a vacuum tube amplifier. The over-all characteristics of the 515 PSA amplifier were 32 db gain from 50 to 150 megacycles with an average noise figure of about 3.5 decibels. This model was delivered to Evans Signal Laboratory on 2 August 1961, and was subsequently subjected to field testing by the military. A photograph of this amplifier appears as Figure 1.

2. 150 to 300 Megacycle Model

The second experimental model to be developed under this contract was the 1530 PSA. This amplifier consisted of a phase shift amplifier followed by a transistorized post amplifier. It has an over-all gain of 26 db (see Figure 2) and an average over-all noise figure of 3.8 db (see Figure 3).

a. The employment of a transistorized post amplifier was made possible by an improvement in the transistor state of the art. When the 515 PSA was built, the vacuum tube unit was necessary since its noise figure was much better than that available with transistors at that time. When the 1530 PSA was

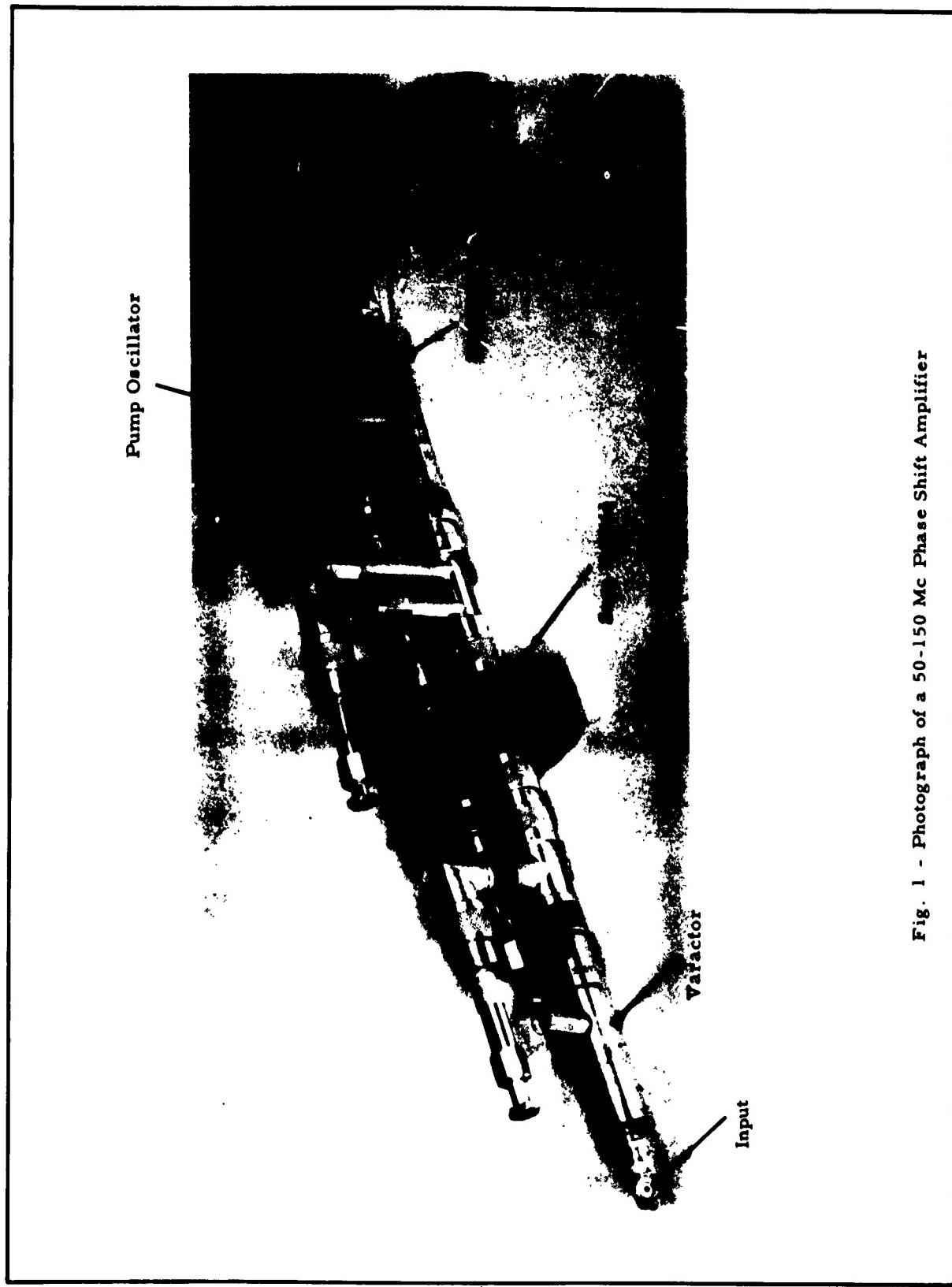


Fig. 1 - Photograph of a 50-150 Mc Phase Shift Amplifier

H R B

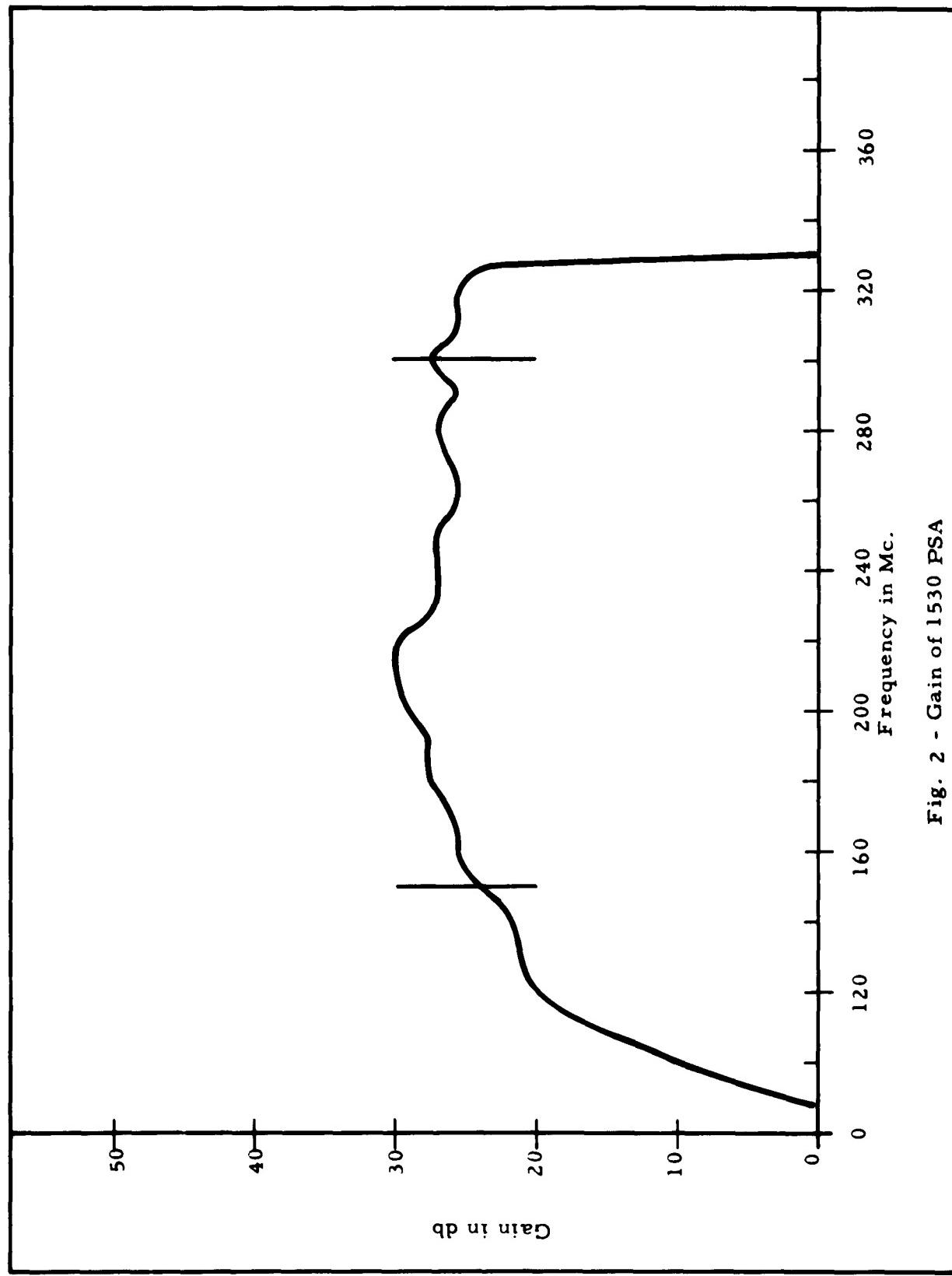


Fig. 2 - Gain of 1530 PSA

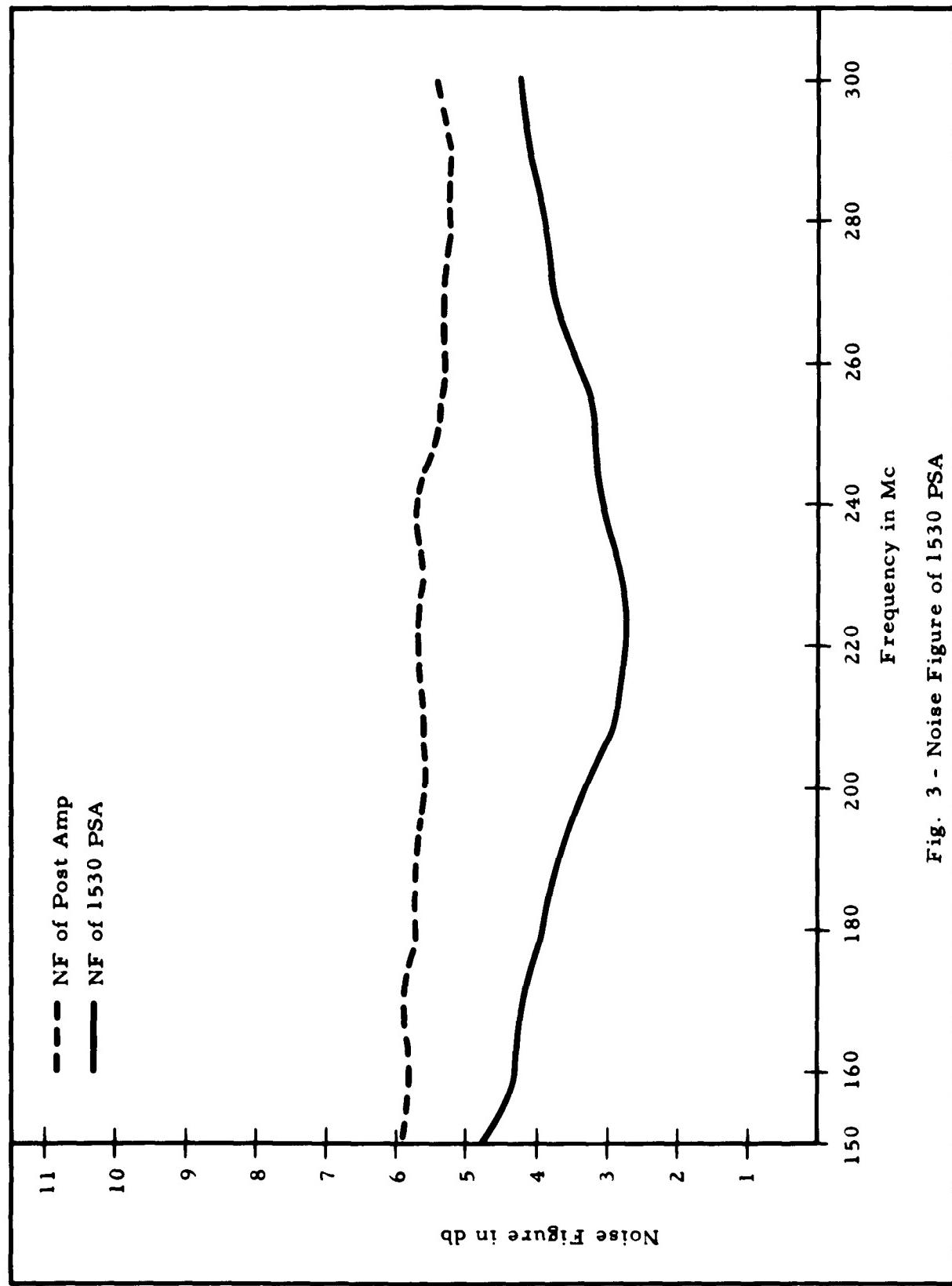


Fig. 3 - Noise Figure of 1530 PSA

built a transistorized amplifier with 5.5 db noise figure was available, allowing an improvement in the size and power requirements for the post amplifier. Photographs for this 1530 PSA appear as Figures 4 and 5.

b. The model 1530 PSA consists of two units: an amplifier unit designed to mount on the antenna mast and a power box designed to mount in a standard 19 inch panel rack. The power supply is transistor regulated and 115 volts 50 or 60 cycles a.c. It supplies 12 volts d. c. to the amplifier unit through the RF cable.

c. The amplifier requires three voltages, 10 volts for the post amplifier, 6 volts for the filaments of the pump oscillator and 150 volts for the plate of the pump oscillator. The plate voltage is obtained from the 12 v d.c. through the employment of a transistor vibrator, a transformer, bridge circuit, filter and regulator which are located within the amplifier unit. The only power which is supplied to the amplifier unit is the 12 volts d.c. which is applied directly to the transistor vibrator circuit, and after being dropped by the proper amount is applied to the pump filaments (6 volts) and the post amplifier (10 volts). The dimensions of the amplifier unit are 4" x 4" x 18". It weighs 5 pounds.

3. Problems Encountered

During the development of these experimental models several difficulties were encountered which should be mentioned.

a. If the amplifier is aligned for gain across the band, it becomes open circuit unstable with regard to the input. This instability remains unless the input is well matched across the entire band of operation. The approximate criterion for stability is a voltage standing wave ratio of less than 3 to 1 against 50 ohms across the entire band of the amplifier, for the load seen by the input.

b. If the amplifier is aligned for gain and bandwidth and its noise figure measured without realignment, its noise figure will usually be high, approximately 6 db. If it is slightly realigned as its noise figure is being monitored an over-all noise figure of approximately 3 db can be obtained. A slight change in response may accompany this noise figure reduction, however, which requires an alternating of gain alignment and alignment for noise figure until the optimum compromise is achieved.

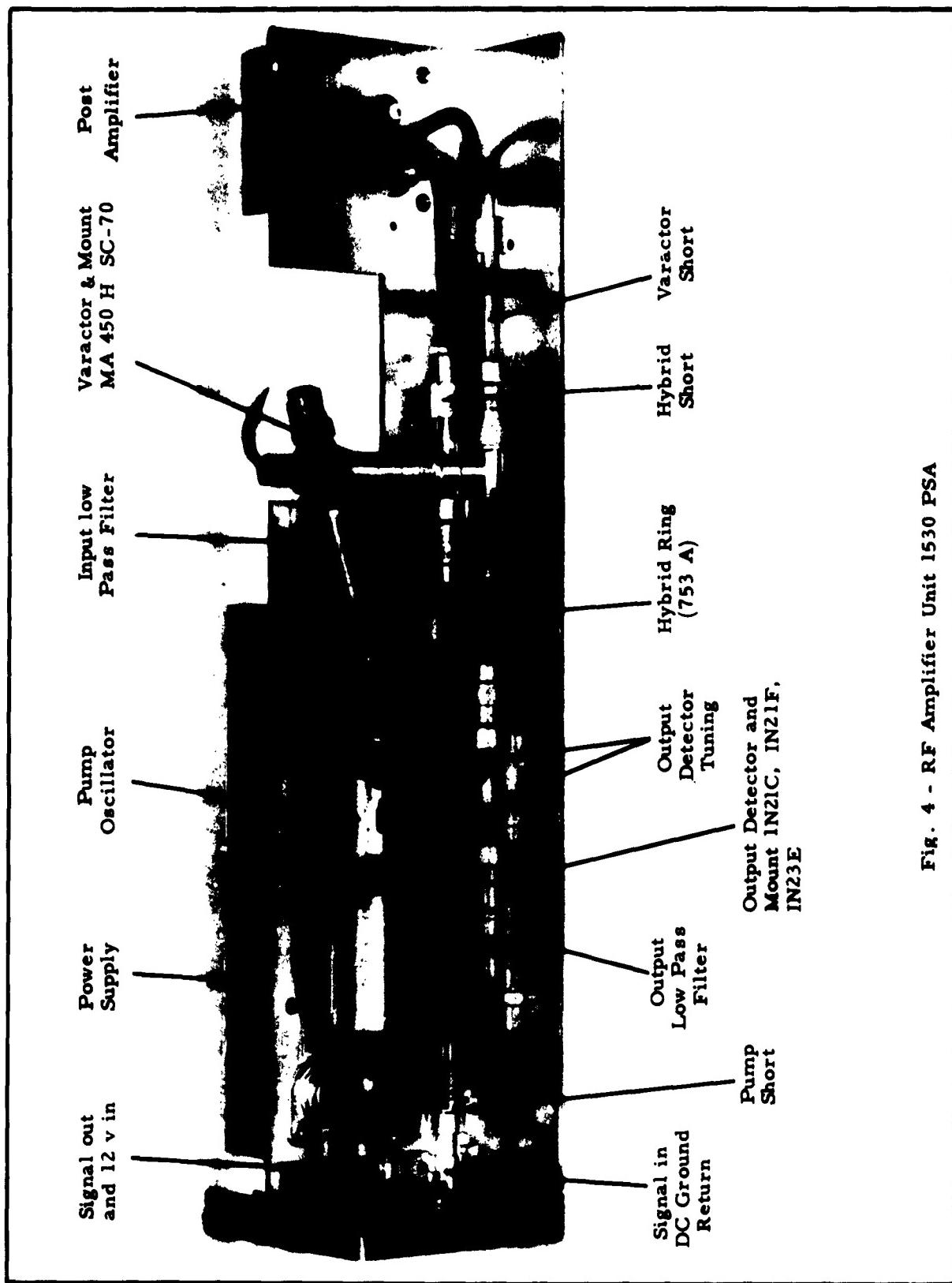


Fig. 4 - RF Amplifier Unit 1530 PSA

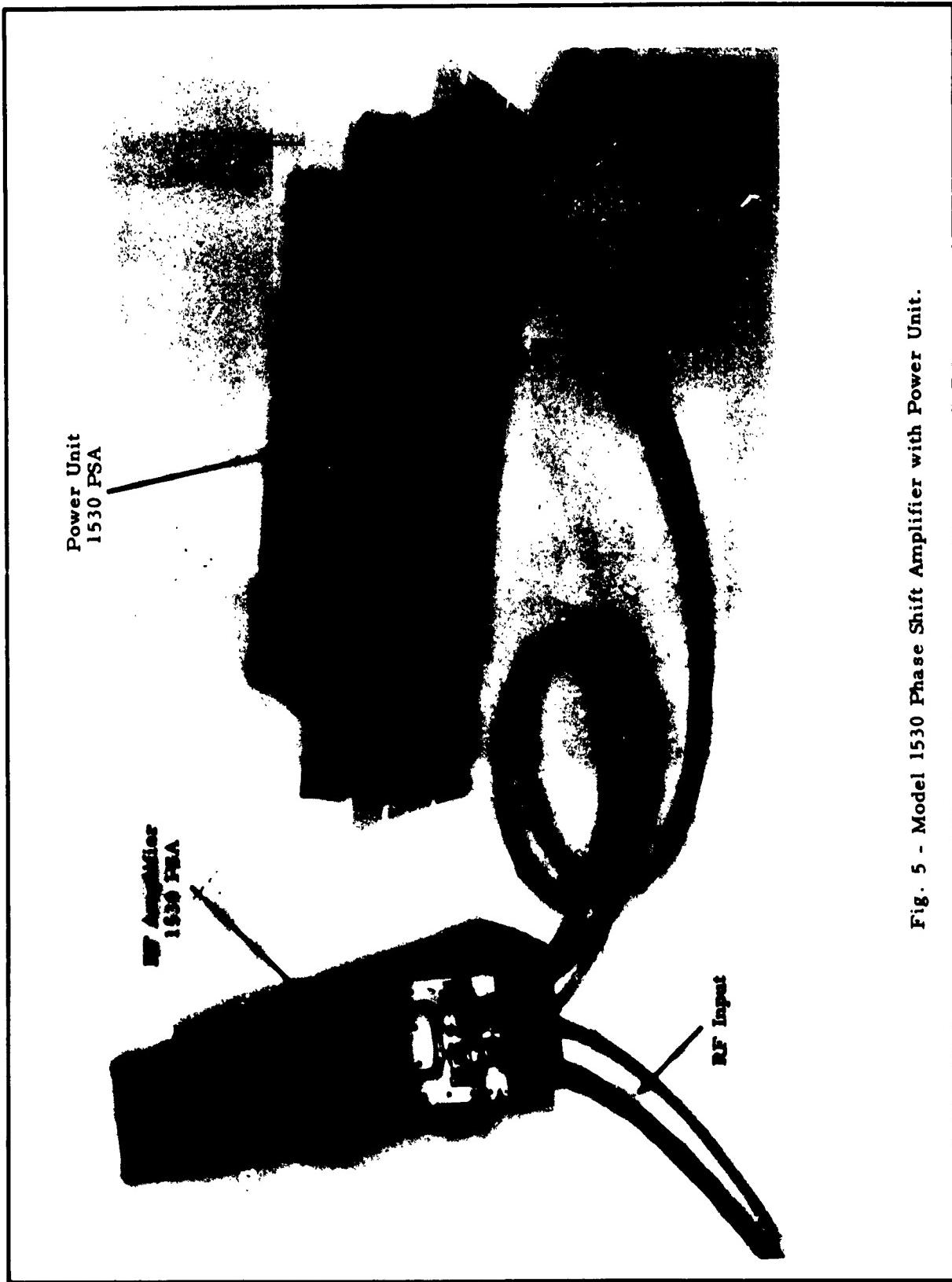


Fig. 5 - Model 1530 Phase Shift Amplifier with Power Unit.

c. The process of aligning the phase shift amplifier often has deleterious effects upon the varactor and crystal. This effect is not dramatic, and frequently can only be observed by replacing the suspected component. Where two varactors may previously have been equivalent, the one which has been used in the alignment process will frequently perform 3 or more db less efficiently. The same degradation of performance occurs with the crystals, although this is more common with high performance 1N21F crystals than with the nearly equivalent 1N21C's. The 1N21C thus appears to be more desirable than the 1N21F.

d. Certain line lengths, which, on an a priori basis, would not appear to be a variable in the amplifier alignment, are quite critical. A particular example of this is the distance from the pump oscillator to the hybrid. If this distance is incorrect, a "hole" in the response will occur, indicating about 10 db less gain at one frequency than across the rest of the band. The frequency at which this loss of gain occurs, and the amount of loss are unaffected by tuning of the pump frequency, and adjustment of the tuning stubs produces only slight effect. It seems that this lack of gain at a single frequency must be due to a resonance at the signal, rather than pump frequency. Why this should be the case is unclear, and exact observations of the relationship between the frequency of the resonance and the length of the pump-to-hybrid path have not been made. It is possible, however, to arrive at a line length such that any resonance which may occur is outside the band.

C. EXPERIMENTAL LABORATORY MODELS

Several laboratory models were assembled to investigate the availability of gain over the 50-1100 Mc band. Actually two models of the phase shift amplifier were assembled and then aligned for various bands. For example, the 250 to 500 and 600 to 1100 megacycle laboratory models were the same circuit employing the same basic components, but in one case the alignment was for 250 to 500 megacycle operation and in the other it was for 600 to 1100 megacycle operation. A coaxial network pumped at 1680 Mcs, and later at S-Band, served as the laboratory model for 50 to 150 and 150 to 300 Mcs. The results of this investigation appear in Report No. 290-2. In summary, the 50 to 1100 megacycle band was investigated for gain with the results shown in

Figure 6. The responses plotted in Figure 6 probably do not represent maximum available gain. The relatively low gain obtained in the 600 to 1100 megacycle band, for example, shows only that gain can be obtained in this band with a small amount of effort. More gain in this band can quite probably be obtained with more effort.

D. INTERMODULATION MEASUREMENTS

Intermodulation measurements were performed on the 250 to 500 megacycle laboratory model. This unit, which was pumped with an X-Band klystron, had a very flat 10 db gain.

1. In order to investigate the intermodulation characteristics of the phase shift amplifier, the circuit shown in Figure 7 was assembled. Two signals of the same power were coupled into the hybrid ring FROM signal generators A and B. The attenuators in the circuit are for the purpose of isolation, and are of course taken into account in determining the power levels present at the receiver input. The hybrid was designed to provide isolation greater than 45 db between signal generators A and B from 250 to 500 megacycles. This is necessary to prevent intermodulation from occurring within the signal generators.

2. Signal generators A and B were separated in frequency by several megacycles. The receiver alone was then searched for spurious signals and intermodulation products. Any such unwanted responses were recorded with their frequency and equivalent power. The term "equivalent power" refers to the power input at the receiver required from the reference signal generator, at the frequency of the unwanted response, to duplicate the unwanted response in the absence of signals from generators A and B. The degree to which a particular response is rejected can be expressed quantitatively. If the input power to the receiver from signal generators A and B and the reference generator are expressed in dbm, the rejection in db is given by:

$$\text{Rejection (in db)} = [\text{Power level (in dbm) of Signals A and B}] - [\text{Equivalent power (in dbm) of response}]$$

OR

$$\left\{ \begin{array}{l} \text{Intermodulation} \\ \text{Rejection} \end{array} \right\} = \frac{\text{Input power of Generator A and B}}{\text{Equivalent power of unwanted response}}$$

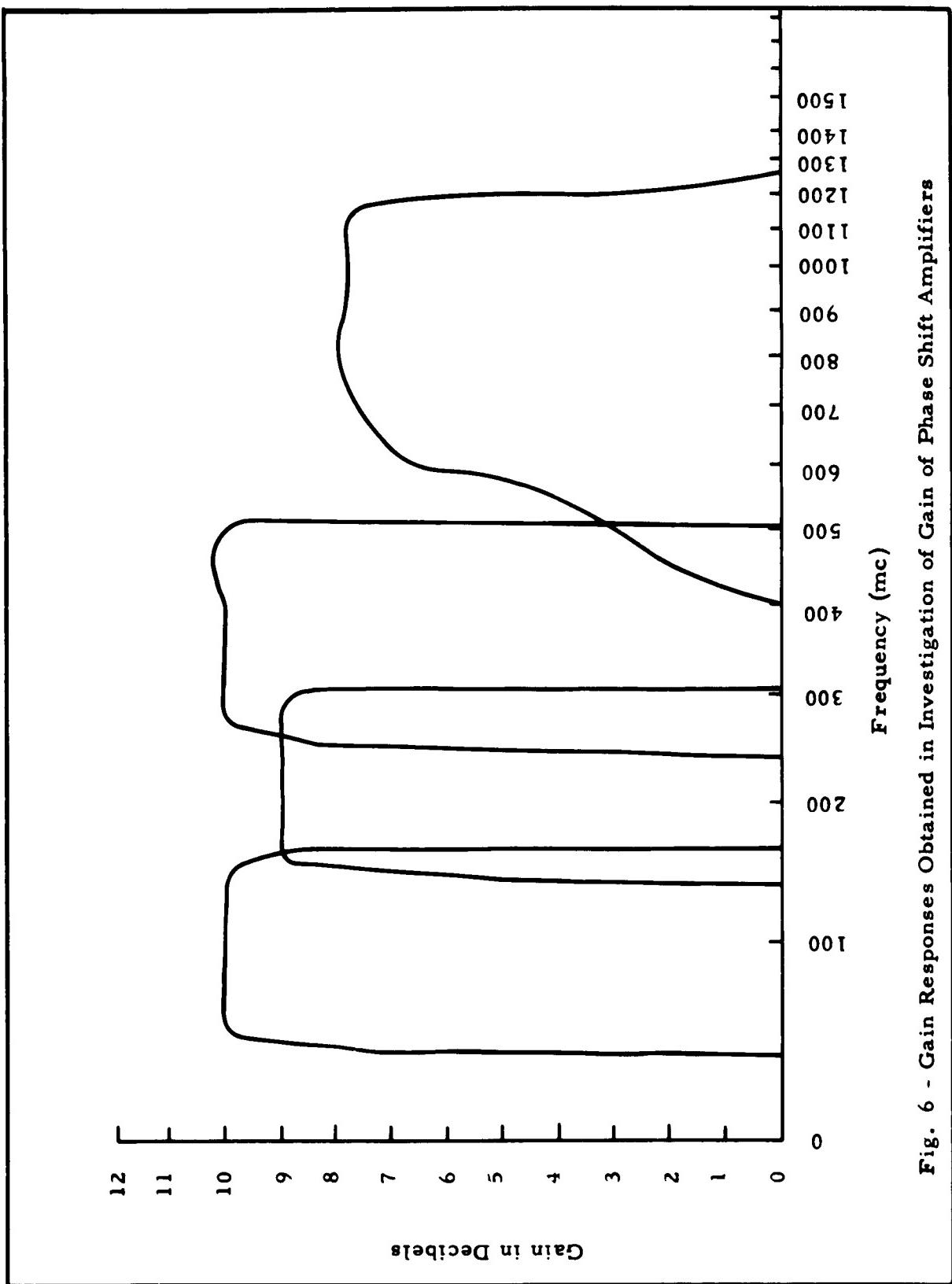


Fig. 6 - Gain Responses Obtained in Investigation of Gain of Phase Shift Amplifiers

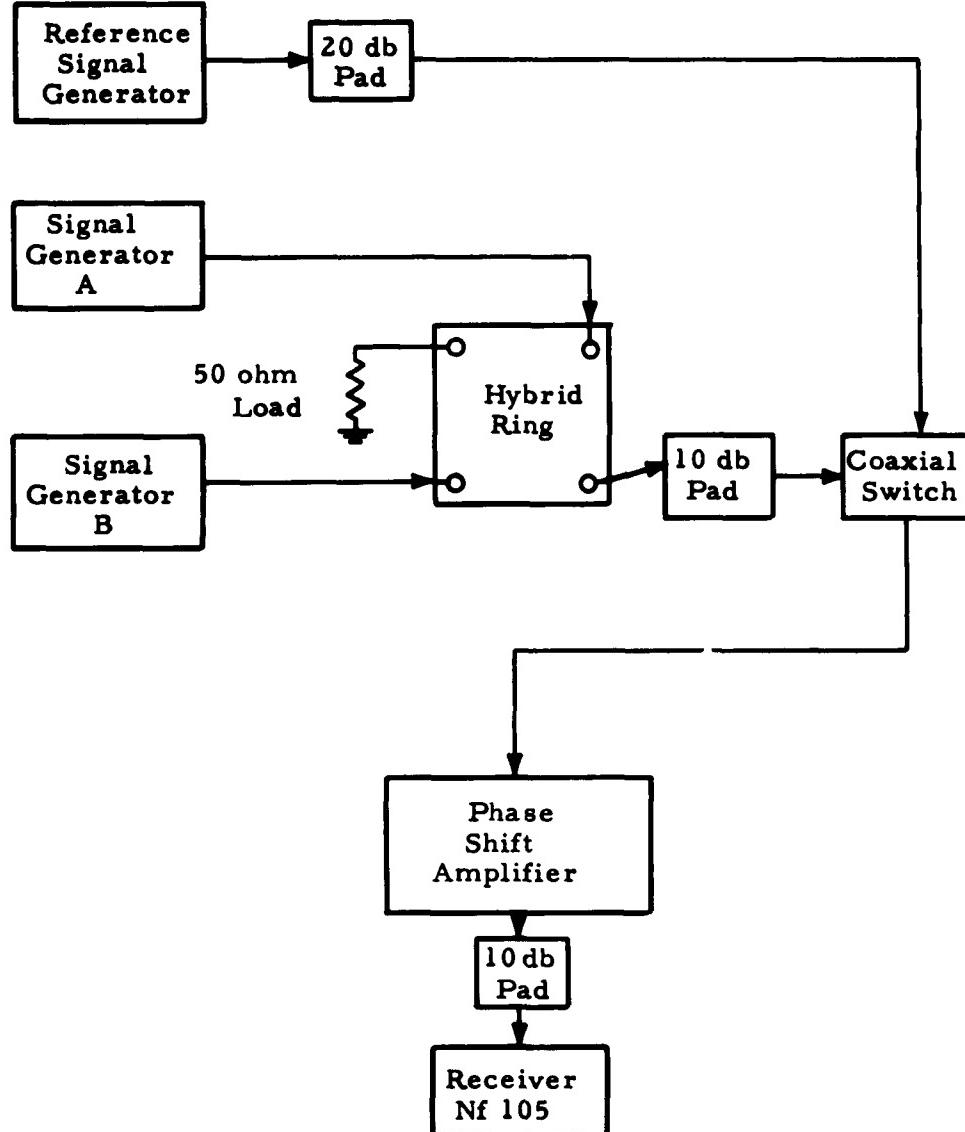


Fig. 7 - Test Configuration Used to Measure Intermodulation Rejection and Cross-Modulation of 1530 PSA

The output of signal generators A and B will hereafter be referred to as signal A and signal B having frequency f_A and f_B respectively.

3. After determining the frequency and equivalent power for the unwanted responses of the receiver alone, the intermodulation characteristics of the amplifier alone were measured by an insertion method. The amplifier under investigation had a very flat 10 db gain across its band. By padding its output 10 db, it could be placed in the circuit with no change in the signal level seen by the receiver. Any change in the responses observed in the receiver can thus be attributed to the amplifier itself. To illustrate this procedure, Figure 8 with its overlay, shows the equivalent power of all of the responses observed in the receiver when preceded by the unity gain amplifier for one setting of generators A and B. The overlay shows only those responses which were present at the same power level in the receiver alone. Raising this overlay will show the equivalent power of those responses due to frequencies generated within the phase shift amplifier.

4. Since the phase shift amplifier employs both a nonlinear capacitance and a nonlinear resistance, the presence of intermodulation would be anticipated. The chief intermodulation problems in the phase shift amplifier arise from odd order products, since its bandwidth is generally less than an octave. Figure 9 shows the frequency of the odd order products which can be anticipated in the presence of two signals separated by a few megacycles. It can readily be seen that these products are evenly spaced on both sides of the mixing signals and are separated in frequency by the same amount ($f_B - f_A$). The higher order products appear only for very high input power, and, for a given input power, the strength of the intermodulation products decreases rapidly as the order increases.

Second order intermodulation products can cause problems if the amplifier has a bandwidth of an octave or more. If the amplifier has an octave bandwidth, signals at the band edges can add or subtract to produce a false signal within the band of the amplifier. (Second order products are those which result from a simple addition or subtraction of the frequency of the two mixing signals).

A summary of the intermodulation rejection for the various order products and for different power levels into the phase shift amplifier and different frequency separation of the mixing signals appears in Table 1.

Spurious Responses of Receiver



Generator B Generator A

Note: Local Oscillator is 20 KHz above tuned frequency.
Power Input from Generators A & B is -20 dBm.

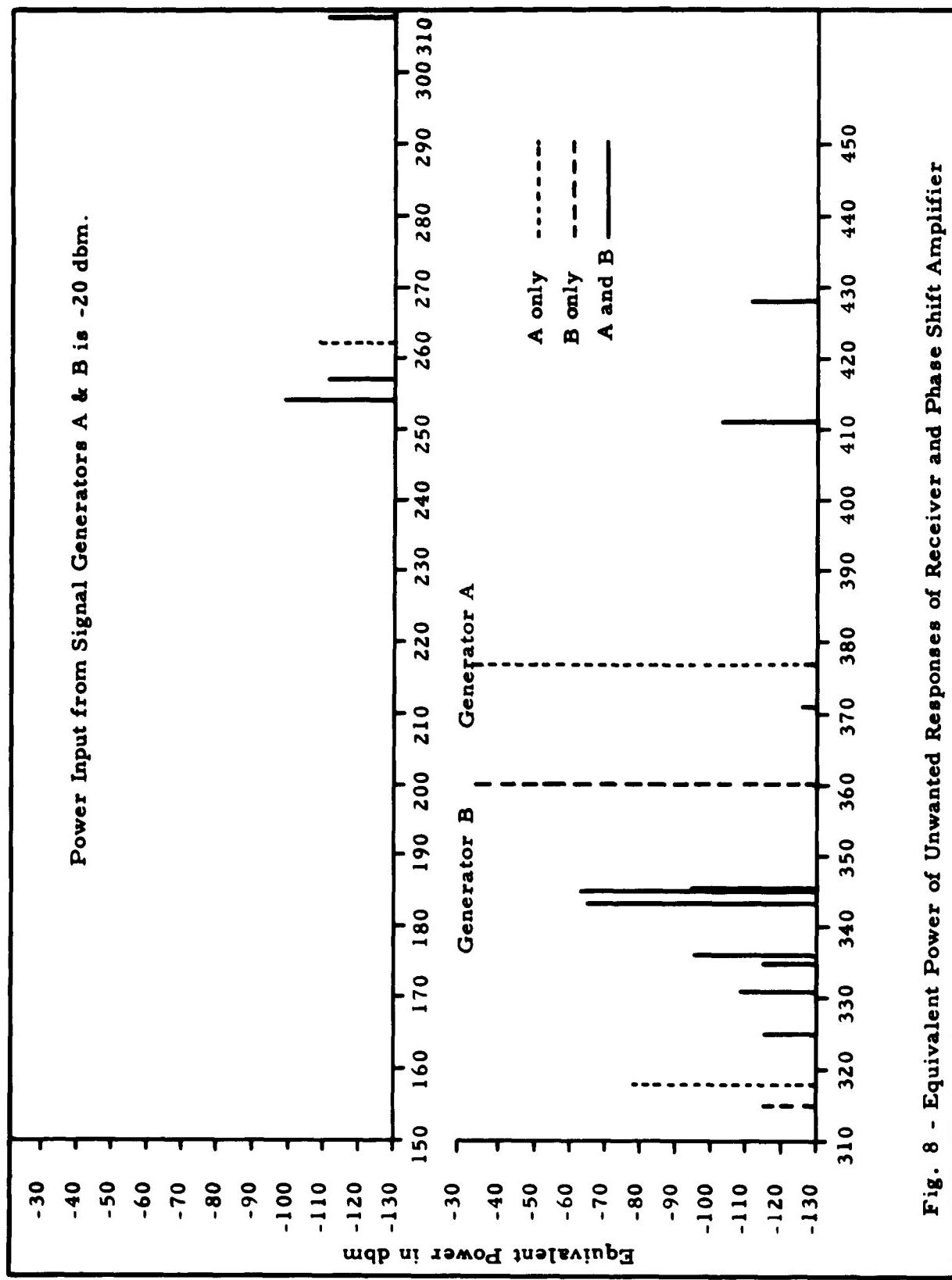


Fig. 8 - Equivalent Power of Unwanted Responses of Receiver and Phase Shift Amplifier

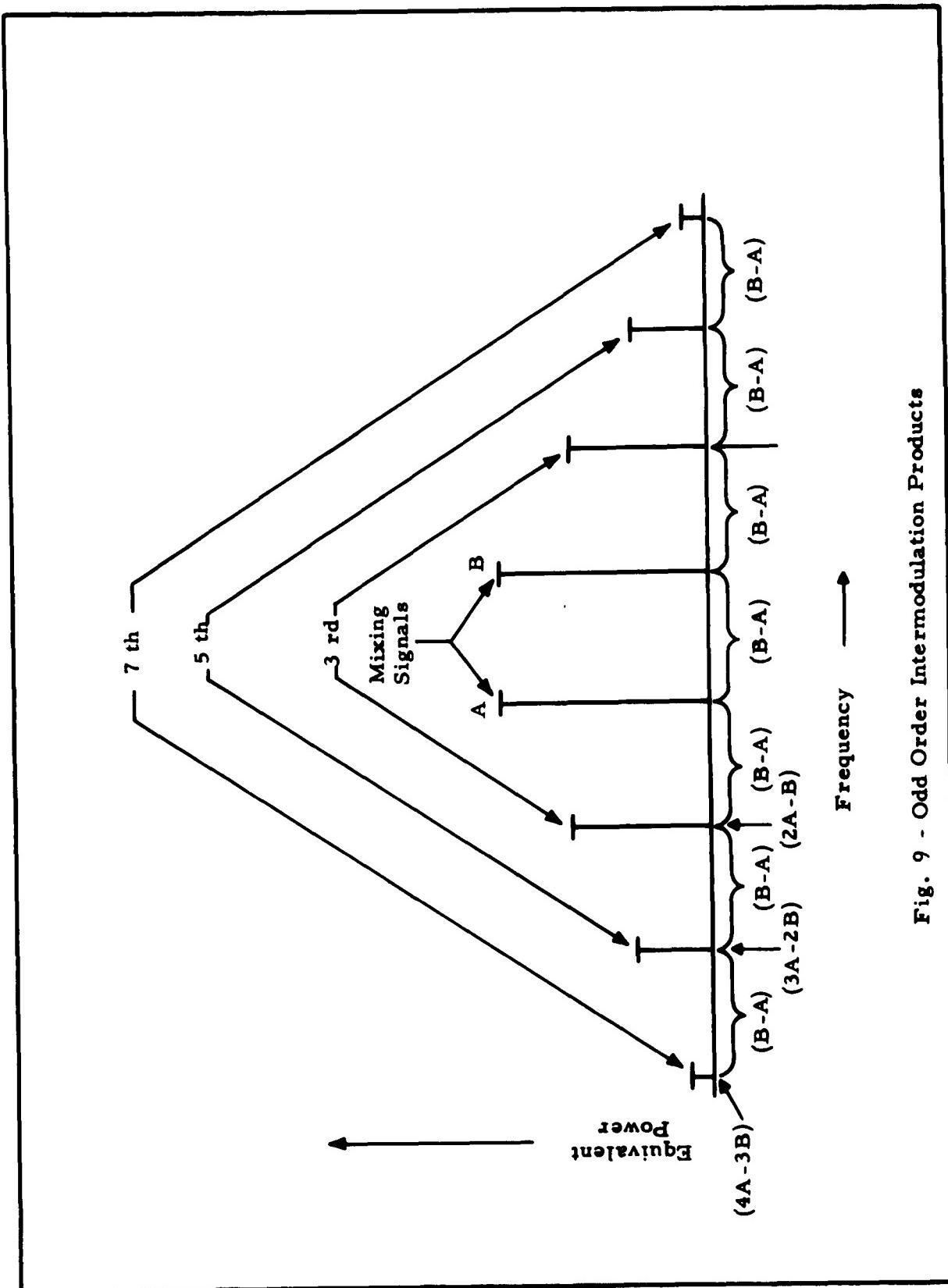


Fig. 9 - Odd Order Intermodulation Products

Table 1 - Intermodulation Rejection of Phase Shift Amplifier for Various Power Inputs and Frequency Separations

Generator A = 337 Mc, Generator B = 360 Mc; Frequency difference = 17 Mc			IM Products Due to Presence of Receiver Local Oscillator in Phase Shift Amplifier		
Signal Generator output -20 dbm at Receiver Input.			Frequency (Mc)	Level (db)	
Odd Order Intermodulation Products					
2nd	5th	7th	180.5	76	
-62	-101	-110 dbm	181	81	
			192.5	81	
			193	79	
			194	88	
			200	91	
IM Products Due to the Presence of the Receiver (NF = 105) Local Oscillator in Phase Shift Amplifier (Local Oscillator Frequency = Tuned Frequency + 30 mc)			201	86	
Frequency Rejection (Mc)	Rejection (db)		202	93	
254	97		221	97	
257	100		222	93	
262	107		223	93	
318	78		235	95	
325	114		236	101	
331	107		250	95	
335	114		250.5	95	
345.5	93		251	105	
371	125		315	105	
Generator A = 377 Mc, Generator B = 360 Mc, Frequency difference = 17 Mc.			316	99	
Signal Generator -40 dbm at Receiver Input.			318	103	
Odd Order Intermodulation Products			320.5	98	
3rd	5th	7th	322	96	
-85 dbm	---	---	340.5	96	
			341	101	
Generator A = 363 Mc, Generator B = 360 Mc, Frequency difference = 3 Mc.			342.5	101	
Signal Generators -20 dbm at Receiver Input.			374.5	115	
Odd Order Intermodulation Products					
3rd	5th	7th			
98 dbm	---	---			

Second Order Intermodulation Products: Generator Levels -20 dbm at receiver input: Frequencies Shown in Mcs.

A = 251 A = 240 A = 240 A = 225 A = 249
 B = 249 B = 241 B = 249 B = 250 B = 248

52 dbm at 500 Mc 57 dbm at 481 55 dbm at 489 50 dbm at 575 50 dbm at 497

E. CROSS-MODULATION MEASUREMENTS

The same basic circuit as employed in the intermodulation measurements was employed to investigate cross-modulation. One of the signal generators (Generator A) was modulated and one (Generator B) remained unmodulated. A measurement of the modulation appearing on B at the receiver was made and a cross modulation factor was computed from the relationship

$$\text{cross-modulation factor} = \frac{\% \text{ modulation on B}}{\% \text{ modulation on A}}$$

A plot of the cross-modulation factor obtained as a function of the frequency separation between A and B appears as Figure 10, for differing power levels of signals A and B.

F. POWER SATURATION MEASUREMENTS

Although the cross modulation and intermodulation characteristics of the phase shift amplifier establish the upper end of its dynamic range at about -40 dbm, power saturation does not occur until the input signal is much stronger. The gain of the amplifier remains constant for signals as strong as -5 dbm. A graph of power in vs. power out appears as Figure 11.

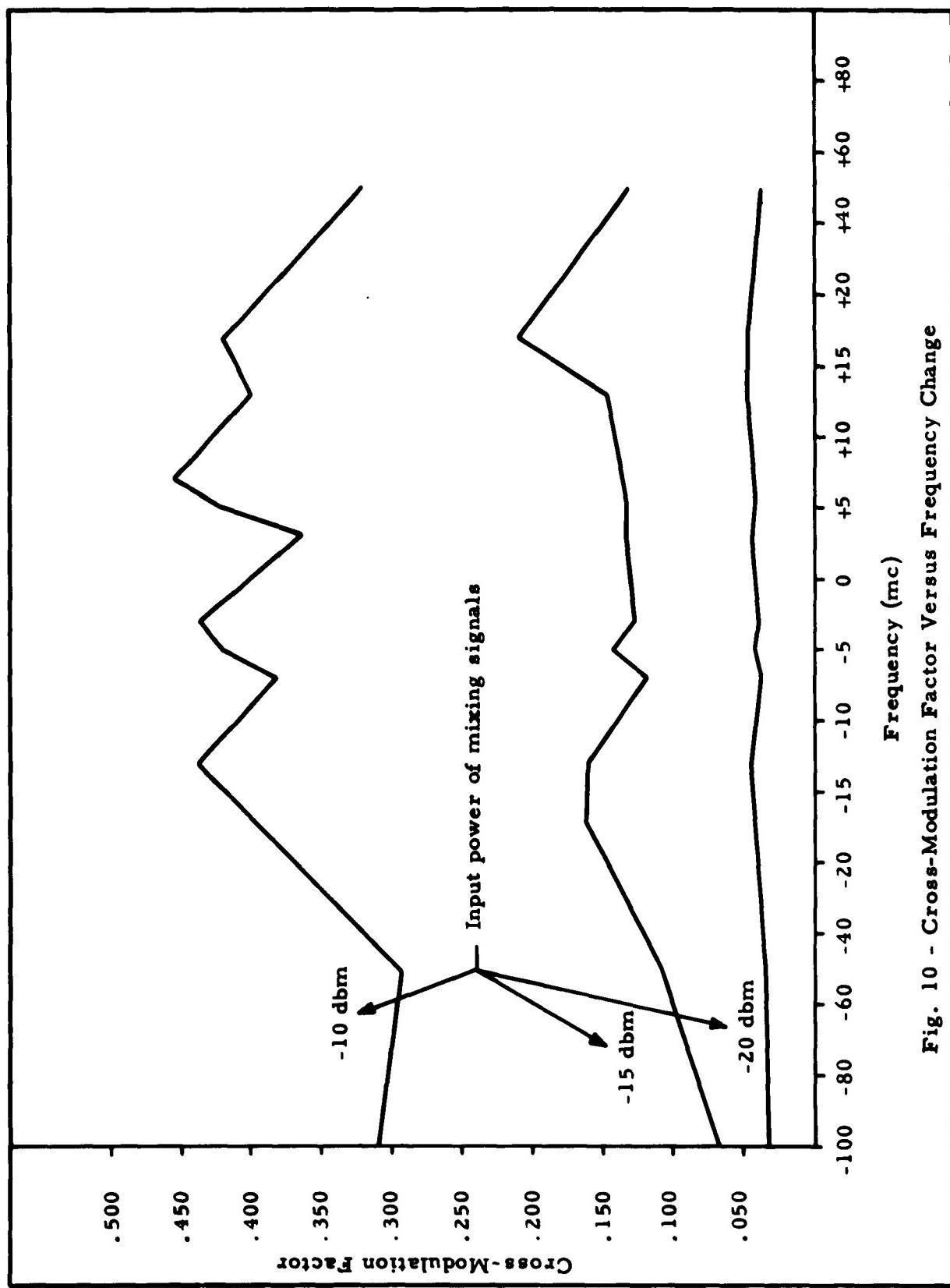


Fig. 10 - Cross-Modulation Factor Versus Frequency Change

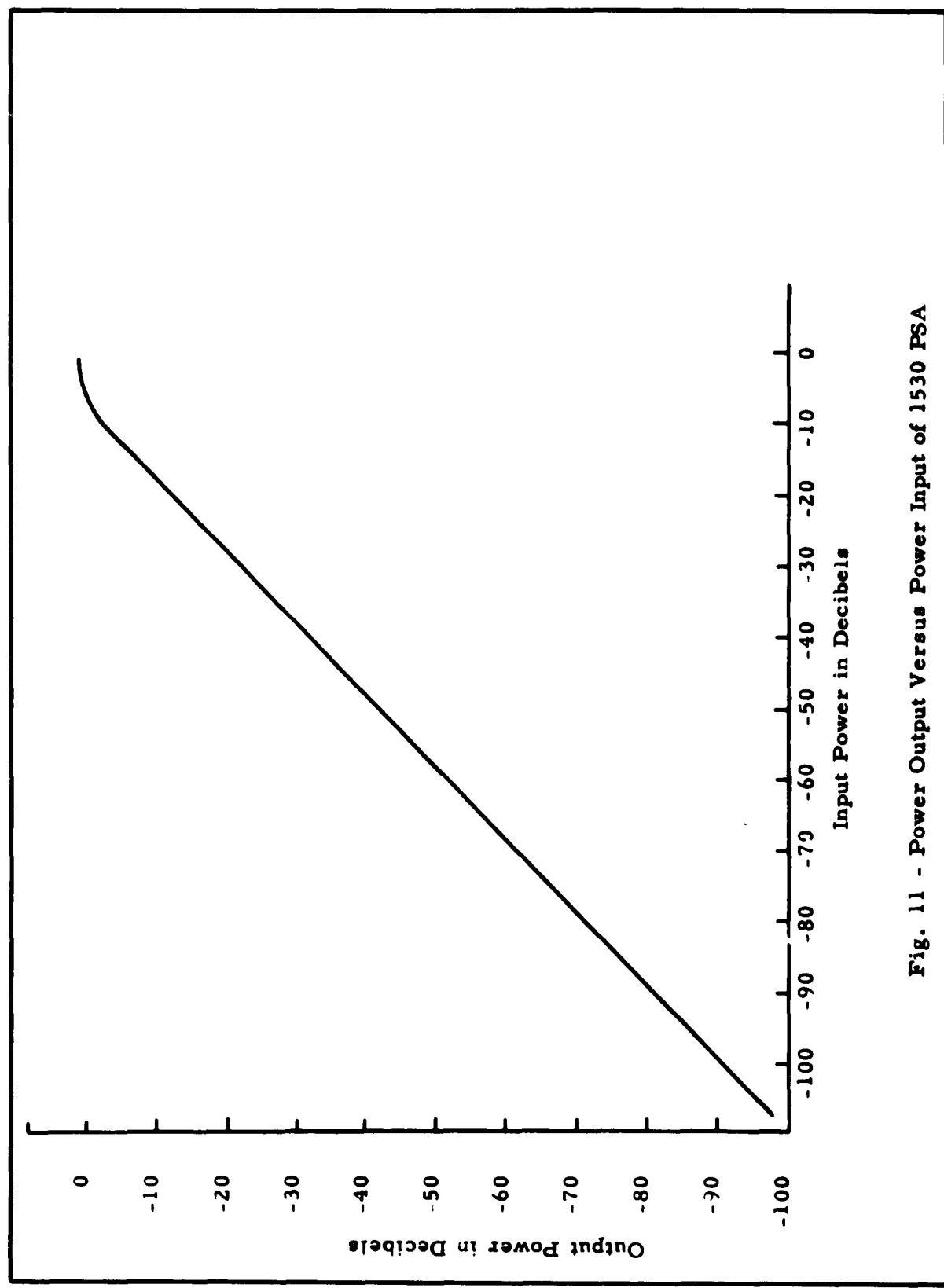


Fig. 11 - Power Output Versus Power Input of 1530 PSA

III. OVER-ALL CONCLUSIONS

A. CAPABILITY OF PHASE SHIFT AMPLIFIER

On the basis of the work accomplished in the laboratory investigations of the phase shift amplifier, it appears that the phase shift amplifier has the capability of providing broadband low noise gain at frequencies as high as eleven hundred megacycles. There seems no reason why 1100 megacycles should be the upper frequency limit of the capability of the phase shift amplifier, however the work covered in the report did not investigate higher frequencies.

B. LIMITATIONS OF PHASE SHIFT AMPLIFIER

The basic limitations of the phase shift amplifier are its intermodulation and cross-modulation characteristics which require it to be employed only in environments where there are no signals, within its band, having a power level greater than minus 40 dbm. For those applications where noise figure is not of primary concern, its power requirements and large physical size are also limitations when compared to transistor amplifiers. At higher frequencies, where transistor amplifiers are not available, the latter limitations become less significant.

IV. RECOMMENDATIONS

A. INVESTIGATION OF SPECIFIC COMPONENTS

To properly exploit the capabilities of the phase shift amplifier, a thorough research effort should be undertaken. The specific components and variables should each be studied thoroughly to determine their effect upon the gain, noise figure and stability of the amplifier. Answers should be obtained to such questions as: what varactor characteristics should be given first concern when choosing a varactor for the amplifier? What pump frequency should be used to amplify a given frequency band? What characteristics should the varactor mount have for application to the phase shift amplifier? These questions all should be answered, yet each requires a thorough study before a correct answer can be given. In a development effort, aimed at producing working models, only partial answers to these (and many other) questions can be obtained. Although a good theoretical analysis of the phase shift amplifier has been performed¹, more detailed work is necessary to obtain information useful to a design engineer. The more detailed work should closely combine theoretical and experimental studies.

B. INVESTIGATION & DEVELOPMENT AT HIGHER FREQUENCIES

Due to the requirement for good low noise broadband amplifiers at frequencies above 1100 megacycles, a laboratory investigation should be undertaken to determine how high in frequency the phase shift amplifier can be employed. The utility and requirement for devices such as the phase shift amplifier are much greater at higher frequencies.

¹D. K. ADAMS, Cooley Electronics Labs, etc.

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